US NRC – PSU Rod Bundle Heat Transfer Program

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The US Nuclear Regulatory Commission and the Penn State University have been developing a new experimental facility which will provide needed and new data on heat transfer and two-phase flow behavior in rod bundles to support the best estimate methods and modeling. The Rod Bundle Heat Transfer (RBHT) Test Facility, which is located at University Park, PA, has been constructed for the expressed purpose of improving the analytical modeling capability of the US Nuclear Regulatory Commission such that best-estimate thermal-hydraulic calculations can be made, with confidence, with reduced uncertainty.

Within the design basis for Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR), the most challenging accident that must be analyzed is the large break, Loss-of-Coolant-Accident (LBLOCA). The LBLOCA is a postulated accident which is not expected to occur, but is analyzed since this particular accident establishes the minimum flow requirements for the Emergency Core Cooling Systems which are designed for either a PWR or BWR to mitigate the consequences of such a transient. The RBHT Facility was designed to perform several different experiments, all of which would help characterize one or more components believed to be important for the modeling and understanding of dispersed flow film boiling in rod bundles. The test facility is a once-through flow facility in which either water or steam can enter the lower plenum and flow upward through the rod bundle. There are liquid collection tanks which are attached to the upper plenum which measure the entrained liquid flow which is carried out of the bundle by the steam. A centrifugal two-phase separator downstream of the upper plenum which also acts to separate out the liquid flow from the vapor flow such that the vortex flow meter at the exit of the steam pipe will measure single phase vapor flow. Separating the exit flows from the bundle provides a method to perform a transient mass balance as well as an energy balance on the facility. The facility has been designed to perform forced reflood tests, with liquid injection into the lower plenum, steam cooling experiments with steam injection into the lower plenum, and steam cooling experiments with droplet injection to simulate dispersed flow film boiling.

There are five pairs of large windows on opposite sides of the housing such that video cameras can be used to film the reflood process as well as using a laser illuminated digital camera system which is used to measure the entrained drop velocity and drop diameters within the rod bundle upstream and downstream of the spacer grids. A laser illuminated digital camera system, developed by Penn State and Oxford Lasers Inc., is being used to measure the entrained drop size and velocity at different axial positions within the bundle in the dispersed flow film boiling regime. The laser system provides back lighting for the very sensitive camera (1000 by 1000 pixels). Drop diameter and droplet velocity distributions are then measured for different time intervals during the transient. Measurements are taken up-stream of a spacer grid as well as downstream to observe the drop shattering effects of the grids and the resulting change in the drop size distribution and mean drop diameters.

The electrical heater rods that are used in the experiments have an outside diameter of 9.5-mm (0.374-inches) and represent a portion of a typical 17 x 17 fuel rod array. The axial power shape represents a top skewed power shape. There are 45 heated electrical rods and four unheated Inconel support rods in the corners of the test assembly which are used to support the spacer grids as well as to bring out instrumentation which is located within the bundle. There are approximately 500 channels of instrumentation for the facility.

In the Rod Bundle Test Facility, improved sub-channel instrumentation was used to measure the vapor temperatures within the rod bundle to detect the presence of superheated vapor in the presence of entrained liquid droplets. The degree of non-equilibrium in the flow depends on the amount of droplets that are entrained and the mixing and heat transfer between the droplets.

To measure the sub-channel vapor superheat, two types of miniature thermocouple probes were used. One type of miniature thermocouple probe was suspended from the spacer grids and would face into the flow. The thermocouples were 0.38 mm in diameter and were supported by 2.44 mm Inconel tubes where were tack welded to the spacer grids. The second vapor superheat measurement uses a traversing thermocouple rake consisting of three, 0.38 thermocouples which were attached to a thin piece of Inconel shim stock and to a tube (which was out of the flow stream) that could be moved to different radial positions within the bundle. The probe could be positioned to measure vapor temperatures in the center of the sub-channel or points in between the sub-channel centers. Figure 1 shows a comparison of the vapor temperature measured during reflood with the traversing probe at the subchannel center and a second identical test with the probe in the gap between the heater rods. The vapor temperature in the gap is almost 200°F higher than the center of the subchannel.

The ability of a best-estimate computer code to accurately predict the integrated effects of the individual phenomena for dispersed flow film boiling is a challenge. Spacer grids have been shown to have a first order effect on the dispersed flow film boiling heat transfer in rod bundles. Therefore, a best estimate computer code must have an explicit model for spacer grids. The effect of spacer grids on the heat transfer and the temperature distribution on the heater rods is seen in Figure 2. The spacer grids improve the heat transfer downstream of the grid. The current focus of the experimental program is to provide improved data for dispersed flow film boiling in prototypical rod bundle geometries. To that end, prototypical spacer grids have been designed, instrumented and tested in the facility. The initial results indicate that the spacer grids can significantly improve the dispersed flow heat transfer downstream of the grids by a combination of increased turbulent mixing as well as shattering of the entrained droplets in the highly non-equilibrium dispersed two-phase flow.

Figure 1

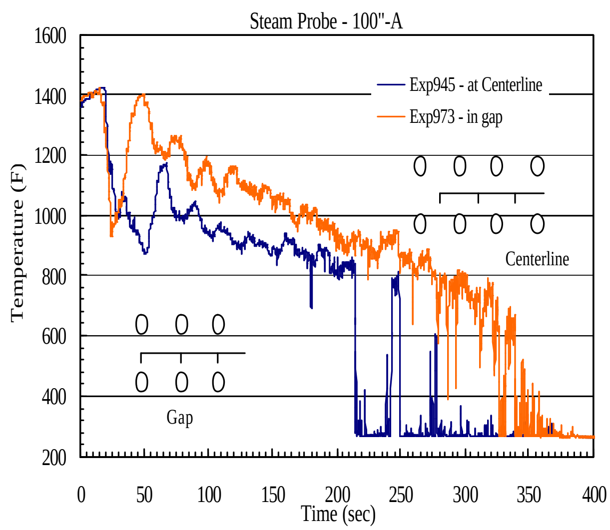

Figure 2